OPTIMIZATION OF TWO BAY PORTAL FRAME

A THESIS SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

By

PRANGYA PARAMITA PRADHAN

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Under the Guidance of

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CERTIFICATE

This is to certify that thesis entitled, "**OPTIMIZATION OF TWO BAY PORTAL FRAMES"** submitted by **Ms. PRANGYA PARAMITA PRADHAN** in partial fulfillment of the requirements for the award of **Bachelor of Technology Degree in Civil Engineering at National Institute of Technology, Rourkela (Deemed University)** is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other university/ institute for award of any Degree or Diploma.

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CONTENTS

ABSTRACT

In the report analysis of two bay frames for both non-sway and lateral sway has been done. Formulae have been derived for the calculation of end moments. Variation of maximum negative and positive moment in the span with D_2 has been done for various cases of varying loads and span and graphs are plotted. A comparison is also done between the graphs obtained from non sway and sway cases.

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1.HISTORY:

1.1.Structural Analysis

A structure is the assemblage of two or more basic structural components connected together in such a way that they serve the user functionally and carry the loads arising out of self and super-imposed loads safely without causing any problem of serviceability. Structural analysis deals with study and determination of forces in various components of a structure subjected to loads.

As the structural system as a whole and the loads acting on it may be of complex nature certain simplifying assumptions with regard to the quality of material, geometry of the members, nature and distribution of loads and the extent of connectivity at the joints and the supports are always made to make the analysis simpler.

1.2.Slope Deflection Method

This method can be used to analyze statically indeterminate structures, composed of moment resisting members such as beams and frames. The basic slope deflection equation expresses the moment at the end of the member as the superposition of end moments due to external loads on the member with the ends assumed restrained and the end moments caused by actual end rotations and displacements. In a structure composed of several members, slope deflection equations are applied to each member of the structure.Using appropriate equation of equilibrium of the joints along with slope deflection equations for each member, we obtain a set of simultaneous equations with displacements as unknowns, With the displacements evaluated, the end moments can be computed usind slope deflection equations.

1.3.Moment Distribution method

This is also known as Hardy cross method.It provides a convenient means of analyzing statically determinate structures(beams and frames) by manual calculations. This is basically an iterative process.

It involves artificially restraining temporarily all the joints against rotations and writing down the fixed end moments for all the members. The joints are then released one by one in succession. At each released member joint the unbalanced moments are distributed to all the ends of the members meeting at that joint.A certain factor of these distributed moments are carried over to the far end of members. The released joint is again restrained temporarily before proceeding to the next joint. The same set of operations are carried out at each joint till all the joints are completed. This completes one cycle of operations.The process is repeated for a number of cycles till the values obtained are within the desired accuracy.

This method is also a displacement analysis.But this method does not involve solving simultaneous equations as in case of slope deflection method. This method is very popular as it is free from solving simultaneous equations if the frames do not undergo lateral deformations

1.4.Kani's Method

This method was provided by Gasper Kani in the year 1947. This method provides a systematic approach for the analysis and design of rigid jointed frames. It is a numerical approach for the solution of slope deflection equations.This is iterative in nature in which the end moments in the members of a rigid jointed skeletal structure are determined by correcting successively the fixed end moments in the corresponding restrained structure, The deformation of a rigid jointed skeletal structure gives rise to

- Joint rotation: Since the joints are rigid, the joint rotations are also the end rotations of the members meeting at the joint.
- Linear displacements of joints resulting in member rotations.

The joint rotation as well as the linear displacements make their own contributions to the end moment in the members of the structure.They are respectively known as rotation contributions and displacement contributions. In Kani's method both these types of contributions are iterated in such a way that the joint equilibrium equations as well as the shear equations, if any, are satisfied at every stage of iteration.

<u>*Kani's method offers the following advantages as compared to moment distribution method*</u>:

- The entire computations are carried out in a single line diagram of the structure.
- The effect of joint rotations and sway are taken into account in each cycle of iteration. So there is no need to solve a set of simultaneous equations. This method thus becomes very useful particularly in case of multistory building frames.
- The method is self correcting, that is, any error in a cycle is corrected automatically in the subsequent cycles. The checking is easier as only the last cycle needs to be checked.
- The convergence is generally fast. It helps to get the solutions in a few cycles of iterations.

2.INTRODUCTION:

2.1.Optimization

- Optimization is referred to as the procedure used to make a system or design as effective or as functional as possible, involving various mathematical techniques. The objective functions, the design variables, the pre assigned parameters and the constraints describe an optimization problem.The quantities which describe an optimization problem, can be divided into two groups: Pre assigned variables and design variables.
- In most practical cases, an infinite number of feasible designs exist. In order to find the best one, it is necessary to form a function of the variables to use it for comparison of design alternatives. The objective function (also termed the cost, or merit function) is the function whose least, or greatest is sought in an optimization procedure.
- The optimization model consists of an objective function and a set of constraints. The set of constraints generally include

  (i) limits of search for the decision variables;

  (ii) various stress conditions and their limits;

  (iii) restrictions on the structural behaviour in terms of slope and deflections of appropriate structural members and joints, respectively; and

  (iv) structural response in terms of bending moments, shear forces, axial forces, and support reactions corresponding to a specified loading condition. The structural

- The different single objective optimization techniques make the designer able to determine the optimum sizes of structures, to get the best solution among several alternatives.The efficiencies of these techniques is different.A large number of algorithms have been proposed for the nonlinear programming solution.The choice of a particular algorithm for any situation depends on the problem formulation and the user. One of the techniques is the use of numerical methods.Numerical methods use past information to generate better solutions to the optimization problem by means of iterative procedures.

2.2.Portal Frames

A frame or frame work is a structural skeleton, which supports the other components of the object. Portal frames are widely used in the construction of large sheds for industrial buildings.They are also used in stiffening large span bridge girders or as viaduct. A portal frame essentially consists of vertical members and top member which may be horizontal, curved or pitched.The vertical and top members are rigidly joined. The frames may be fixed or hinged at the base.

A simple portal frame consists of a horizontal beam resting on two columns. The junction of the beam with the column consists of rigid joints. If the loading is symmetrical,there will be no joint translation or sway.

<u>3.METHODOLOGY ADOPTED</u>:

Dr. Gasper Kani's method of iteration is by far the most accurate method for analyzing Multistory, Multibay frames with translatory joints with or without horizontal loads such as wind load etc.

According to an article on "Frame analysis" in the journal of the Institution of Engineers (India) Vide vol. XIV 11, No.7, P & CI 4 march 1967, it was proved that the kani's method of iteration is in geometric progression and summation yields most accurate results without undergoing much labor required for an iteration process.

The singular advantage of this new procedure is that any joint in the frame can be analyzed whereas in Kani's procedure of iteration all the joints in a frame have to be analyzed before near end moments at one end of bar is determined

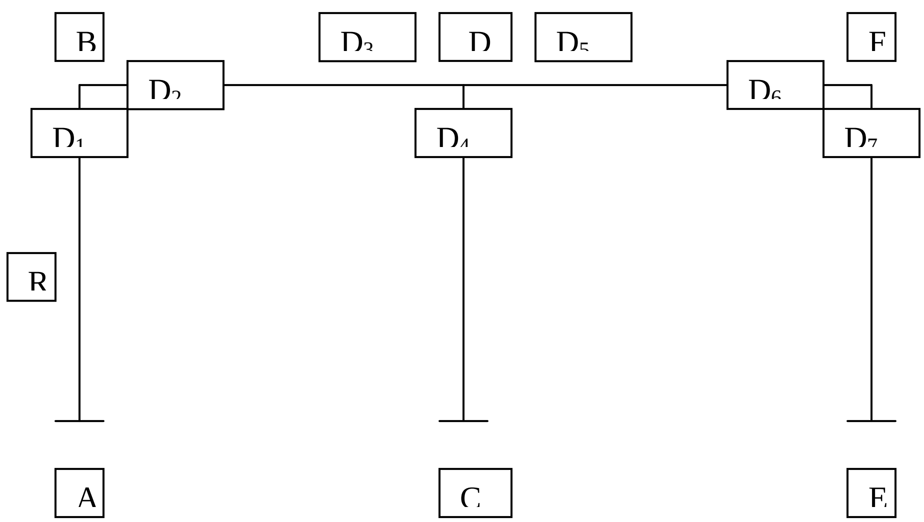


Fig.3.1

For 2-BAY FRAMES the basic equations involved are (including lateral sway due to vertical laoding} :

$M_{BD}=M^F_{BD} + 2\,M'_{BD} + M'_{DB} + M''_{AB}$

$M_{DB}=M^F_{DB} + 2\ M'_{DB} + M'_{BD} + M''_{AB}$

$M_{DF}=M^F_{DF} + 2\ M'_{DF} + M'_{FD} + M''_{AB}$

$M_{FD}=M^F_{FD} + 2\ M'_{FD} + M'_{DF} + M''_{AB}$

The rotation contribution at the near end B in the member BD

$M'_{BD} = R_{BD} * [(\sum M^F_B) + (\sum M'_{DB})]$

$\sum M^F_B$ =sum of fixed end moments at joint B

$\sum M'_{DB}$ =sum of rotation contributions at far ends A and D

R_{BD} = Rotation factor at the near end B in the member given by the equation

$= [(m*K_{BD})/(\sum m* K_{BD})]*(-1/2)$

Where far ends are: 1.fixed, m=1; 2.hinged, m=3/4

$\sum m* K_{BD}$ represents the sum of the relative stiffnesses of all the members connected at the joint considered.

The displacement contribution for for the storey

$M''_{AB} = R\ (\sum M'_{AB} + \sum M'_{BA})$

Where, R = Displacement factor of AB = $[K_{AB} / \sum K_{AB}]*(-3/2)$

$(\sum M'_{AB} + \sum M'_{BA})$ represents the sum of the rotation contributions of the top and bottom ends of all the columns of the storey considered.

$\sum K_{AB}$ represents the sum of the relative stiffnesses of all the columns of the storey considered.

Initial unbalanced moment at B(for beam BD) = M_1

Initial unbalanced moment at D (for beam BD)= M_2

Initial unbalanced moment at D (for beam DF)= M_3

Initial unbalanced moment at F (for beam DF)= M_4

4.ANALYSIS OF FRAMES WITHOUT LATERAL SWAY:

4.1. FOR EQUAL LOADING AND SPAN IN BOTH BAYS:

a.Derivation of the formulae

Derivation of the formulae on the basis of Kani's method of iteration explained below:

Table 4.1

$M_5=M_2-M_3$

	$-M_1$	M_2	$-M_3$	M_4
	$-D_2$	$-D_3$	$-D_5$	$-D_6$
1	M_1D_2	$-M_5D_3$	$-M_5D_5$	$-M_4D_6$
2	M_1D_2+ $M_5D_2D_3$	$-M_5D_3-M_1D_2D_3+$ $M_4D_3D_6$	$-M_5D_5-M_1D_2D_5+$ $M_4D_5D_6$	$-M_4D_6+$ $M_5D_5D_6$
3	M_1D_2+ $M_5D_2D_3+$ $M_1D_2^2D_3-$ $M_4D_2D_3D_6$	$-M_5D_3-M_1D_2D_3-$ $M_5D_3^2D_2+M_4D_3D_6$ $-M_5D_3D_5D_6$	$-M_5D_5-M_1D_2D_5-$ $M_5D_2D_3D_5+$ $M_4D_5D_6$ $-M_5D_5^2D_6$	$-M_4D_6+$ $M_5D_5D_6+$ $M_1D_2D_5D_6-$ $M_4D_6^2D_5$
4	M_1D_2+ $M_5D_2D_3+$ $M_1D_2^2D_3+$ $M_5D_2^2D_3^2-$ $M_4D_2D_3D_6+$ $M_5D_2D_3D_5D_6$	$-M_5D_3-M_1D_2D_3-$ $M_5D_3^2D_2-$ $M_1D_2^2D_3^2+$ $M_4D_3D_6+$ $M_4D_2D_3^2D_6-$ $M_5D_3D_5D_6-$ $M_1D_2D_3D_5D_6+$ $M_4D_3D_5D_6^2$	$-M_5D_5-M_1D_2D_5$ $-M_5D_2D_3D_5-$ $M_1D_2^2D_3D_5+$ $M_4D_2D_3D_5D_6+$ $M_4D_5D_6-$ $M_5D_5^2D_6-$ $M_1D_2D_5^2D_6+$ $M_4D_5^2D_6^2$	$-M_4D_6+$ $M_5D_5D_6+$ $M_1D_2D_5D_6+$ $M_5D_2D_3D_5D_6$ $-M_4D_6^2D_5$ $+M_5D_5^2D_6^2$
5	M_1D_2+ $M_5D_2D_3+$ $M_1D_2^2D_3+$ $M_5D_2^2D_3^{2+}$ $M_1D_2^3D_3^2-$ $M_4D_2^2D_3^2D_6-$ $M_4D_2D_3D_6+$ $M_5D_2D_3D_5D_6+$ $M_1D_2^2D_3D_5D_6-$ $M_4D_2D_3D_5D_6^2$	$-M_5D_3-M_1D_2D_3-$ $M_5D_3^2D_2-$ $M_1D_2^2D_3^2-$ $M_5D_2^2D_3^2+$ $M_4D_2D_3^2D_6-$ $M_5D_3^2D_2D_5D_6$ $M_4D_3D_6-$ $M_5D_3D_5D_6-$ $M_1D_2D_3D_5D_6-$ $M_5D_3^2D_2D_5D_6+$ $M_4D_3D_5D_6^2-$ $M_5D_5^2D_6^2D_3$	$-M_5D_5-M_1D_2D_5$ $-M_5D_2D_3D_5-$ $M_1D_2^2D_3D_5-$ $M_5D_2^2D_3^2D_5+$ $M_4D_2D_3D_5D_6-$ $M_5D_2D_3D_6D_5^2+$ $M_4D_5D_6-M_5D_5^2D_6-$ $M_1D_2D_5^2D_6-$ $M_5D_2D_3D_6D_5^2+$ $M_4D_5^2D_6^2-$ $M_5D_5^3D_6^2$	$-M_4D_6+$ $M_5D_5D_6+$ $M_1D_2D_5D_6+$ $M_5D_2D_3D_5D_6+$ $M_1D_2^2D_3D_5D_6-$ $M_4D_2D_3D_5D_6^2$ $-M_4D_6^2D_5$ $+M_5D_5^2D_6^2+$ $M_1D_5^2D_6^2D_2-$ $M_4D_5^2D_6^3$

From above after distribution to infinity,

Consider $D_2 = D_6$

$D_3 = D_5$

& $M_5 = 0$ i.e. $(M_2 = M_3)$

For BD,

$M_1D_2 + D_2^2D_3(M_1 – M_4)[1+ 2 D_2D_3 + (2 D_2D_3)^2 + (2 D_2D_3)^3 +\ldots\ldots\ldots\ldots]$

It is in geometric progression, the summation = a/(1-r) , where a is the first term, the common ratio= r = 2 D_2D_3 (<1), a= 1

So summation, $M'_{BD} = M_1D_2 + D_2^2D_3(M_1 – M_4) / (1- 2 D_2D_3)$

Similarly, $M'_{FD} = -M_4D_2 + D_2^2D_3(M_1 – M_4) / (1- 2 D_2D_3)$

Also, $M'_{DB} = M'_{DF}$

Summation is(for 2nd and 3rd terms)

$D_2D_3(M_4 – M_1) [1+ 2 D_2D_3 + (2 D_2D_3)^2 + (2 D_2D_3)^3 +\ldots\ldots\ldots\ldots]$

So $M'_{DB} = M'_{DF} = D_2D_3(M_4 – M_1) / (1- 2 D_2D_3)$

FINAL MOMENT = Fixed end moment + 2*Near end moment + Far end moment

$M_{BD} = M^F_{BD} + 2 M'_{BD} + M'_{DB}$

$= - M_1 + 2[M_1D_2 + D_2^2D_3(M_1 – M_4) / (1- 2 D_2D_3)] + D_2D_3(M_4 – M_1) / (1- 2 D_2D_3)$

Now taking $M_1 = M_4,$

$M_{BD} = - M_1 + 2 M_1D_2$

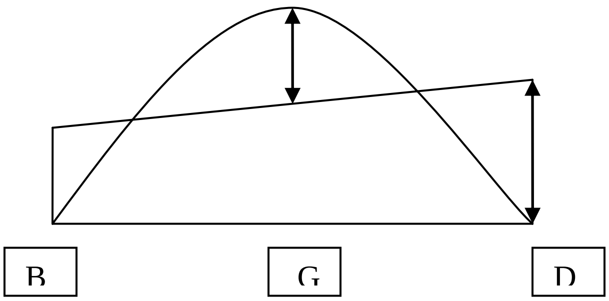
$= M_1(2 D_2 -1)$

Similarly,

$M_{DB} = M_1(D_2 +1)$

$M_{DF} = - M_1(D_2 +1)$; $M_{FD} = - M_1(2 D_2 -1)$

b.ANALYSIS:



Final design moments for BD

$M_B = M_1(2D_2 - 1)$

$M_D = M_1(D_2 + 1)$

So,

$M_G = [M_1(2D_2 - 1) + M_1(D_2 + 1)]/2$

$\quad = (M_1 D_2)(3/2)$

In case of a UDL on the beam, the fixed end moment at the end= $M_1 = (w*l^2)/12$

s/s mid span moment = $(w*l^2)/8$

The final moment at the end should be such that the net positive and negative moment in the beam are equal.So

$(3/2) M_1 - (M_1 D_2)(3/2) = M_1(D_2 + 1)$

Or, $D_2 = 0.2$

So the rotation factor in the beam remains constant even with the increase in the loading.

Now, $D_{Beam} = D_2 = [K_{Beam}/(K_{Beam} + K_{Column})]*(1/2)$

Or, $K_{Column} = K_{Beam}(1-2D_2)/(2D_2)$

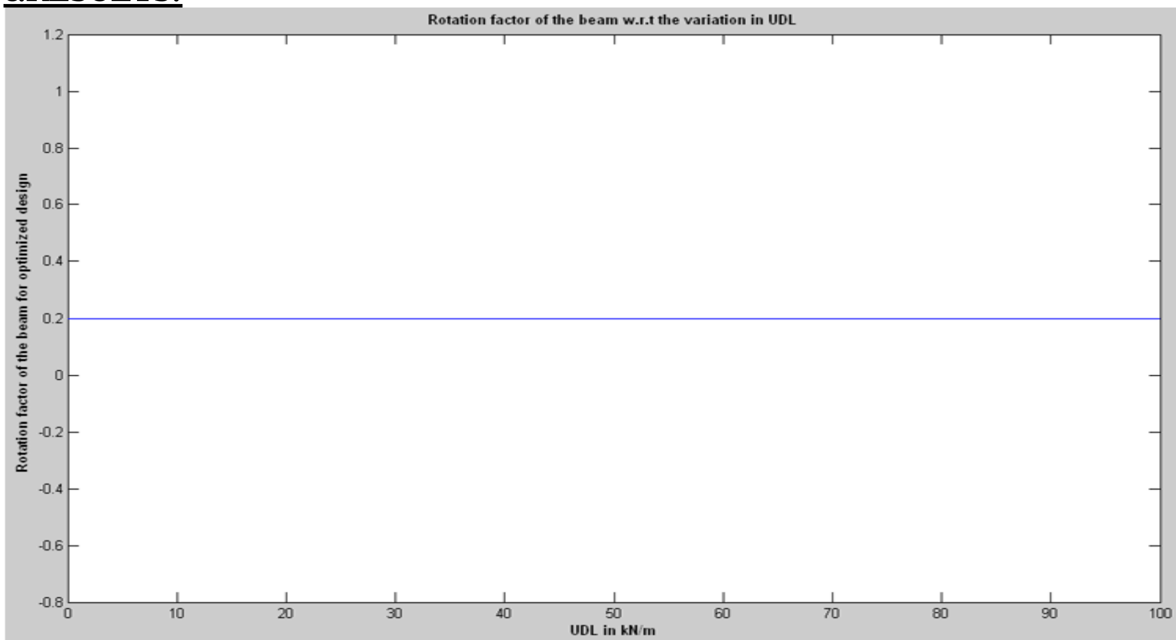
So, the relation between ratio of the depth of the column to the depth of the beam with the ratio of height of the column to the span of the beam is as below;

$(D_{Column} / D_{Beam}) = \sqrt[3]{[(1-2 D_2)/ (2 D_2)* (H_{Column} / l_{Beam})]}$

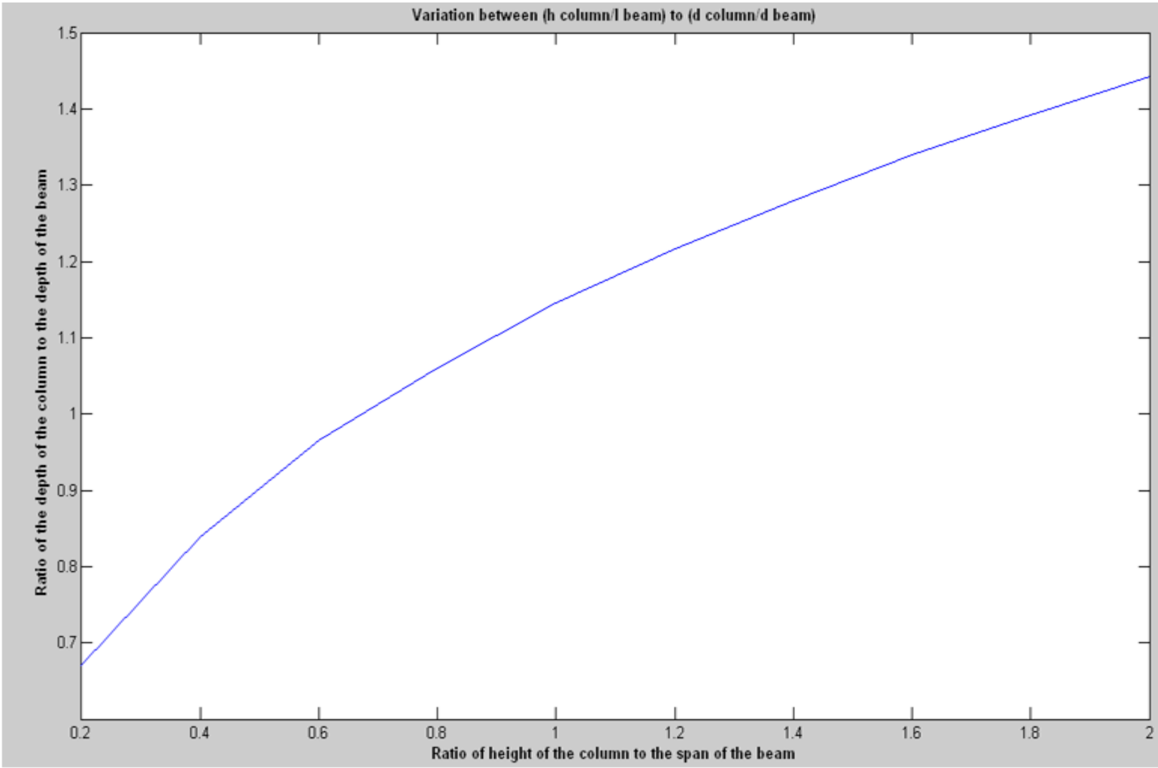
(As the width of the column and the width of the beam is same throughout so cancels from both sides)

So a graph can be plotted showing the variation of ratio of the depth of the column to the depth of the beam with the increase in the ratio of height of the column to the span of the beam

c.RESULTS:



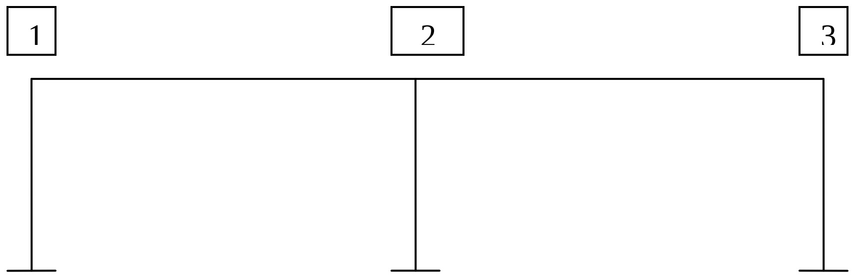
The inference of the graph is that rotation factor of the beam remains constant with the increase in loading on the frame.



The inference from the graph is that with increase in the height of the column wrt the span of the beam, the depth of column will also increase wrt the depth of the beam for optimized design.

4.2.GENERALIZED FORMULAE:

(Final end moments)



After 9 iterations, Rotation contributions:

$$M_{12}' = M_1D_2 + (D_2D_3)(M_5 + M_1D_2 - M_4D_6)[1 + (D_2D_3) + (D_2D_3)^2 + \ldots]$$
$$+ (D_5D_6)(D_2D_3)(M_5 + M_1D_2 - M_4D_6)[1 + (D_2D_3) + (D_2D_3)^2 + \ldots]$$
$$+ (D_5D_6)^2(D_2D_3)(M_5 + M_1D_2 - M_4D_6)[1 + (D_2D_3) + (D_2D_3)^2 + \ldots]$$
$$= M_1D_2 + [(D_3D_2)(M_5 + M_1D_2 - M_4D_6)]/[(1-D_2D_3)(1-D_5D_6)]$$

$$M_{21}' = -(D_3)(M_5 + M_1D_2 - M_4D_6)[1 + (D_2D_3) + (D_2D_3)^2 + \ldots]$$
$$- (D_5D_6)(D_3)(M_5 + M_1D_2 - M_4D_6)[1 + (D_2D_3) + (D_2D_3)^2 + \ldots]$$
$$- (D_5D_6)^2(D_3)(M_5 + M_1D_2 - M_4D_6)[1 + (D_2D_3) + (D_2D_3)^2 + \ldots]$$
$$= -[(D_3)(M_5 + M_1D_2 - M_4D_6)]/[(1-D_2D_3)(1-D_5D_6)]$$

$$M_{23}' = -[(D_5)(M_5 + M_1D_2 - M_4D_6)]/[(1-D_2D_3)(1-D_5D_6)]$$

$$M_{32}' = -M_4D_6 + [(D_5D_6)(M_5 + M_1D_2 - M_4D_6)]/[(1-D_2D_3)(1-D_5D_6)]$$

The equations are:

$$M_{12} = M_1(2D_2-1) + [(D_3)(2D_2-1)(M_5 + M_1D_2 - M_4D_6)]/[(1-D_2D_3)(1-D_5D_6)]$$

$$M_{21} = M_1(1+D_2) + [(D_3)(D_2-2)(M_5 + M_1D_2 - M_4D_6)]/[(1-D_2D_3)(1-D_5D_6)]$$

$$M_{23} = -M_4(1+D_6) + [(D_5)(D_6-2)(M_5 + M_1D_2 - M_4D_6)]/[(1-D_2D_3)(1-D_5D_6)]$$

$$M_{32} = M_4(1-2D_6) + [(D_5)(2D_6-1)(M_5 + M_1D_2 - M_4D_6)]/[(1-D_2D_3)(1-D_5D_6)]$$

5.ANALYSIS OF FRAMES WITH LATERAL SWAY:

5.1.DERIVATION OF FORMULAE: (*Table.5.1)*

cycle	(Jt.A)*($-D_1$) Or($-D_2$)	(Jt.B)*($-D_3$) or ($-D_4$) or ($-D_5$)	(Jt.C)*($-D_6$) Or ($-D_7$)	(Column)*(-R)
1	$-M_1$	M_5	M_4	(#)
2	$-M_1 - M_5D_3 - (\#)R$	$M_5+(M_1D_2-M_4D_6) + (\#)R$	$M_4 - M_5D_5 - (\#)R$	$(\#) + M_5(D_1D_3+D_5D_7) -- (M_1D_2-M_4D_6)D_4 + (\#)(D_1+D_4+D_7)R$
3	$-M_1 -M_5D_3- (M_1D_2-M_4D_6)D_3 +(\#)RD_3 - (\#)R - M_5(D_1D_3+D_5D_7)R +(M_1D_2-M_4D_6)D_4R -(\#)(D_1+D_4+D_7)R^2$	$M_5+(M_1D_2-M_4D_6)+ M_5(D_2D_3+D_5D_6) +(\#)(D_2+D_6)R-(\#)R- M_5(D_1D_3+D_5D_7)R+ (M_1D_2-M_4D_6)D_4R - (\#)(D_1+D_4+D_7)R^2$	$M_4 -M_5D_5- (M_1D_2-M_4D_6)D_5 +(\#)RD_5 - (\#)R - M_5(D_1D_3+D_5D_7)R +(M_1D_2-M_4D_6)D_4R -(\#)(D_1+D_4+D_7)R^2$	$(\#) + M_5(D_1D_3+D_5D_7) - (M_1D_2-M_4D_6)D_4 + (M_1D_2-M_4D_6)(D_1D_3+D_5D_7) - M_5(D_2D_3+D_5D_6) D_4 -(\#)(D_1D_3+D_5D_7)R - (\#)(D_2+D_6)R D_4 +(\#)(D_1+D_4+D_7)R +M_5(D_1D_3+D_5D_7)(D_1+D_4+D_7)R - (M_1D_2-M_4D_6)(D_1+D_4+D_7)R D_4 +(\#)(D_1+D_4+D_7)^2R^2$
4	$-M_1 -M_5D_3- (M_1D_2-M_4D_6)D_3 - M_5(D_2D_3+D_5D_6) D_3-(\#)(D_2+ D_6)RD_3 + (\#)RD_3 +M_5(D_1D_3+D_5D_7)R D_3 +(M_1D_2-M_4D_6)D_4R D_3 +(\#)(D_1+D_4+D_7)R^2 D_3 - (\#)R - M_5(D_1D_3+D_5D_7)R +(M_1D_2-M_4D_6)D_4R - (M_1D_2-M_4D_6)(D_1D_3+D_5D_7)R + M_5(D_2D_3+D_5D_6) RD_3 +(\#)(D_1D_3+D_5D_7)R^2 +(\#)(D_2+D_6)R^2 D_4 - (\#)(D_1+D_4+D_7)R^2 - M_5(D_1D_3+D_5D_7)(D_1+D_4+D_7)R^2 +(M_1D_2-M_4D_6)(D_1+D_4+D_7)R^2 D_4 - (\#)(D_1+D_4+D_7)^2R^3$	$M_5+ (Jt.A_{cy.3})*(-D_2) + (Jt.C_{cy.3})*(-D_6) + (Column_{cy.3})*(-R)$	$M_4 -M_5D_5- (M_1D_2-M_4D_6)D_5 - M_5(D_2D_3+D_5D_6) D_5-(\#)(D_2+ D_6)RD_5 + (\#)RD_5 +M_5(D_1D_3+D_5D_7)R D_5 +(M_1D_2-M_4D_6)D_4R D_5 +(\#)(D_1+D_4+D_7)R^2 D_5 - (\#)R - M_5(D_1D_3+D_5D_7)R +(M_1D_2-M_4D_6)D_4R - (M_1D_2-M_4D_6)(D_1D_3+D_5D_7)R + M_5(D_2D_3+D_5D_6) RD_5 +(\#)(D_1D_3+D_5D_7)R^2 +(\#)(D_2+D_6)R^2 D_4 - (\#)(D_1+D_4+D_7)R^2 - M_5(D_1D_3+D_5D_7)(D_1+D_4+D_7)R^2 +(M_1D_2-M_4D_6)(D_1+D_4+D_7)R^2 D_4 - (\#)(D_1+D_4+D_7)^2R^3$	

THE EQUATIONS ARE:

M_{AB} = $-M_1$ -2(Jt.A)D_2 –(Jt.B)D_3 + X

M_{BA} = M_2 -2(Jt.B)D_3 –(Jt.A)D_2 + X

M_{BC} = $-M_3$ -2(Jt.B)D_5 –(Jt.C)D_6 + X

M_{CB} = $-M_1$ -2(Jt.C)D_6 –(Jt.B)D_5 + X

Where,

Jt.A = $-M_1 - M_5D_3$ –(*)D_3/(1-RD_4) +(#)(RD_3)/($) +X

Jt.B = $M_1D_2-M_4D_6 + M_5/(1-(D_2D_3+D_5D_6))$+ (*)($D_2D_3+D_5D_6$)/(1-$RD_4$) +(#)R($D_2+D_6-$

$D_2D_3-D_5D_6$)/($) +[(o)-(*)$D_4$]R($D_2+D_6$)/($) +X

Jt.C = $M_4 - M_5D_5$ –(*)D_5/(1-RD_4) +(#)(RD_5)/($) +X

Symbols:

(#) = ($M_1D_1-M_5D_4-M_4D_7$)

(*) = $M_1D_2-M_4D_6+M_5(D_2D_3+D_5D_6)$

(o) = ($M_1D_2-M_4D_6$ +M_5)($D_1D_3+D_5D_7$)

X = -(#)R/($) –(o)R/($) +(*)D_4R/($)

6.VARIATIONS OF M_P/M_1 AND M_N/M_1 WITH D_2:COMPARISION BETWEEN NON-SWAY AND SWAY CASES

(M_P = Max. positive moment in the span;
M_N = Max. negative moment in the span)

CASE-I: FOR EQUAL LOADING AND SPAN IN BOTH BAYS

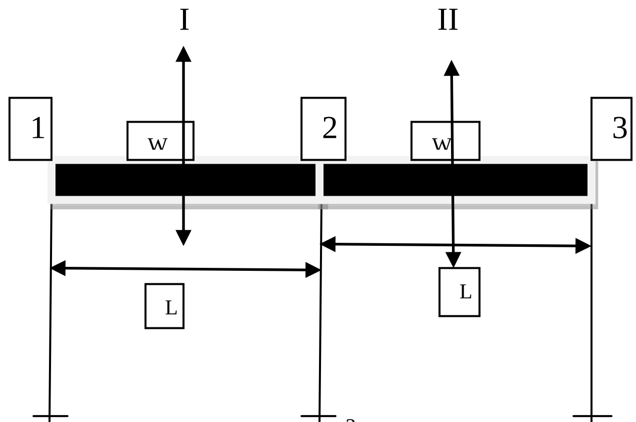


fig.6.1

$M_1=M_4$; $M_5= M_1-M_4=0$; $M_1 = wl^2/12$; S/S moment at mid span, $M_S= wl^2/8 = 1.5M_1$

$D_2=D_6$; $D_5=D_3$

Final end moments:

$M_{12} = M_1*(2*D_2 -1)$; $M_{21} = M_1*(D_2 +1)$

$M_{23} = -M_1*(D_2 +1)$; $M_{32} = -M_1*(2*D_2 -1)$

Mid span moment(-ve):

$M_I = (- M_{12} + M_{12})/2 = [M_1(2-D_2)]/2$

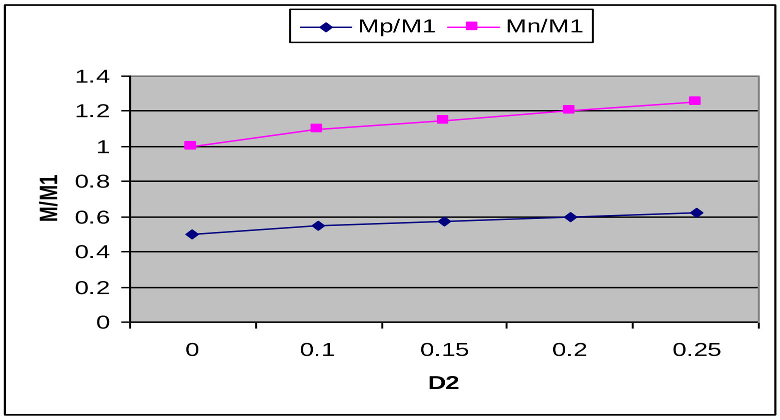
$M_P = M_S – M_I = [M_1(1+D_2)]/2$

$M_N = M_{21}$

FOR BOTH BAYS;

Table 6.1

D_2	M_N /M_1	M_P/M_1
0	-1	0.5
0.1	-1.1	0.55
0.15	-1.15	0.575
0.2	-1.2	0.6
0.25	-1.25	0.625



CASE-II: FOR VARYING LOAD AND EQUAL SPAN

A. LOADS(w,w/2):

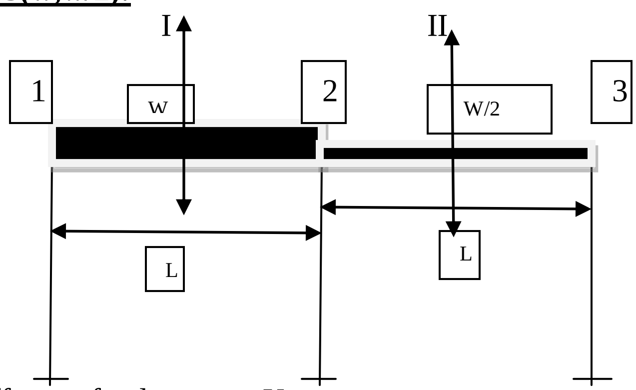


Fig.6.2

Let the stiffness of column $= K_1$

Stiffness of beams $= K_2$

$D_2 = D_6 = [K_2/(K_1 + K_2)]*(1/2);$

$D_5 = D_3 = [K_2/(K_1 + 2K_2)]*(1/2) = D_2/(1+D_2)$

$M_1 = wl^2/12$; $M_4 = wl^2/24 = M_1/2$

$M_5 = M_1 - M_4 = wl^2/24 = M_1/2$

NON-SWAY CASE:

Final end moments:

$M_{12} = [M_1(2D_2 - 1)(2+D_3-3D_2D_3)]/[2(1-2D_2D_3)]$

$M_{21} = [M_1(1+D_2)(2-2D_3-3D_2D_3)]/[2(1-2D_2D_3]$

$M_{23} = [M_1(1+D_2)(3D_2D_3-2D_3-1)]/[2(1-2D_2D_3)]$

$M_{32} = [M_1(1\text{-}2D_2)(1\text{-}D_3\text{-}3D_2D_3)]/[2(1\text{-}2D_2D_3)]$

Mid span moment(-ve):

$M_I \;\; = (- M_{12} + M_{12})/2 = [M_1(4\text{-}2D_2\text{-}D_3\text{-}10D_2D_3\text{-}3D_2^2D_3)]/[4(1\text{-}2D_2D_3]$

$M_{I\,I} \;\; = (- M_{23} + M_{32})/2 = [M_1(2\text{-}D_2\text{+}D_3\text{-}2D_2D_3\text{+}3D_2^2D_3)]/[4(1\text{-}2D_2D_3]$

S/S moment at mid span,:

Bay I: $M_{SI} = wl^2/8 = 1.5M_1$

Bay II: $M_{SII} = wl^2/16 = 0.75M_1$

FOR BAY I: $M_P = M_{SI} – M_I$; $M_N = M_{21}$ (*Table 6.2)*

D_2	D_3	M_N / M_1	M_P/M_1
0	0	-1	0.5
0.1	0.083	-1.01	0.576
0.15	0.115	-1.02	0.62
0.2	0.143	-1.04	0.65
0.25	0.167	-1.05	0.70

FOR BAY II: $M_P = M_{SII} – M_{II}$; $M_N = M_{23}$ (*Table 6.3)*

D_2	D_3	M_N / M_1	M_P/M_1
0	0	-0.5	0.25
0.1	0.083	-0.64	0.249
0.15	0.115	-0.70	0.248
0.2	0.143	-0.76	0.245
0.25	0.167	-0.82	0.241

SWAY CASE:

FOR BAY I: (*Table 6.4)*

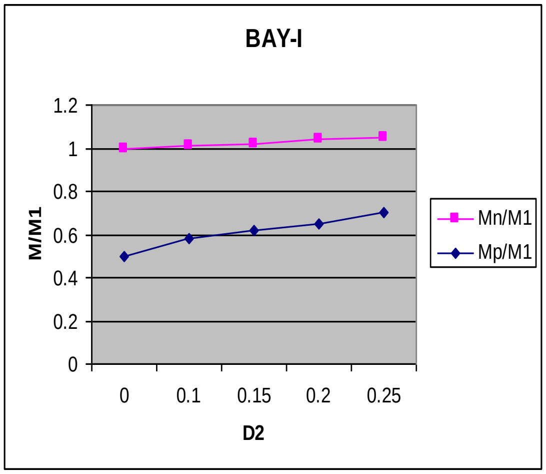
D_2	Jt.A	Jt. B	Jt. C	M_{AB}/M_1	M_{BA}/M_1 (Mn/M_1)	$M_{C/C}/M_1 = (1.5M_1\text{-}M_{11)/} /M_1$
0.1	-1.102	0.512	0.398	-0.88	-0.967	0.576
0.15	-1.124	0.554	0.376	-0.785	-0.982	0.616
0.2	-1.143	0.602	0.356	-0.685	-0.999	0.657
0.25	-1.158	0.658	0.341	-0.581	-1.020	0.700

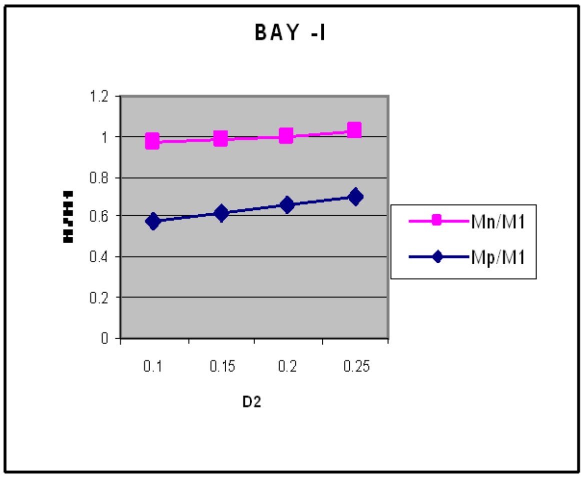
FOR BAY II: *(Table 6.5)*

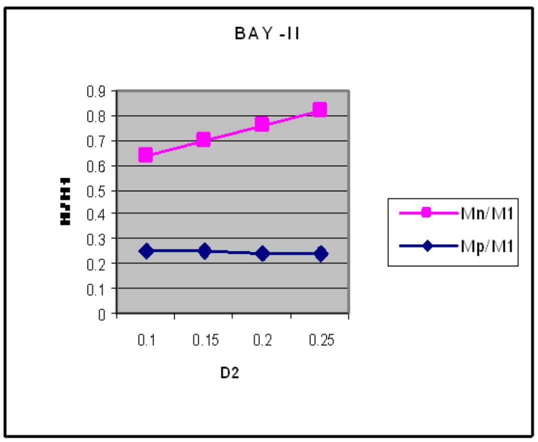
D_2	Jt.A	Jt. B	Jt. C	M_{BC}/M_1 (Mn/M_1)	M_{CB}/M_1	$M_{C/C}/M_1$ = ($0.75M_1$- $M_{22)/}$ /M_1
0.1	-1.102	0.512	0.398	-0.683	-0.32	0.249
0.15	-1.124	0.554	0.376	-0.743	-0.264	0.246
0.2	-1.143	0.602	0.356	-0.8	-0.215	0.242
0.25	-1.158	0.658	0.341	-0.855	-0.17	0.238

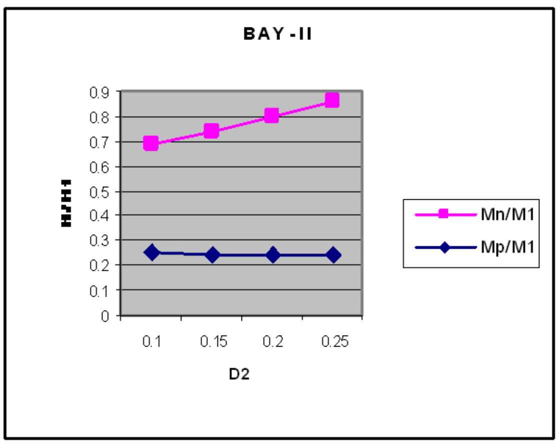
NON-SWAY CASE

SWAY CASE









B. LOADS(w,w/4):

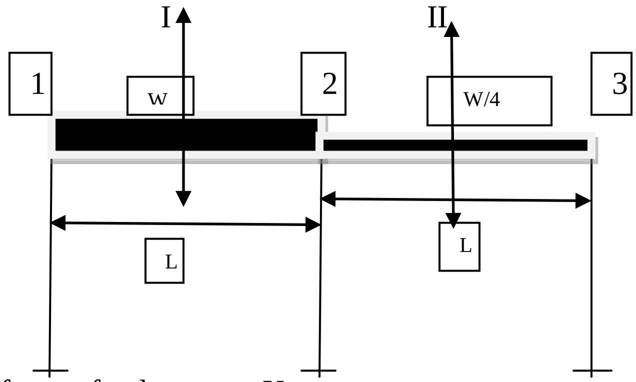


fig.6.3

Let the stiffness of column = K_1

Stiffness of beams = K_2

$D_2=D_6 = [K_2/(K_1 + K_2)]*(1/2);$

$D_5=D_3 = [K_2/(K_1 +2 K_2)]*(1/2) = D_2/(1+D_2)$

$M_1 = wl^2/12$; $M_4 = wl^2/48 = M_1/4$

$M_5= M_1-M_4= 3wl^2/48 = 3M_1/4$

NON-SWAY CASE

Final end moments:

$M_{12} = [M_1(2D_2 -1)(4+3D_3-5D_2D_3)]/[4(1-2D_2D_3)]$

$M_{21} = [M_1(1+D_2)(4-6D_3-5D_2D_3)]/[4(1-2D_2D_3]$

$M_{23} = [M_1(1+D_2)(5D_2D_3-6D_3-1)]/[4(1-2D_2D_3)]$

$M_{32} = [M_1(1-2D_2)(1-3D_3-5D_2D_3)]/[4(1-2D_2D_3)]$

Mid span moment(-ve):

$M_I = (- M_{12} + M_{12})/2 = [M_1(8-4D_2-3D_3-22D_2D_3-5D_2^2D_3)]/[4(1-2D_2D_3]$

$M_{II} = (- M_{23} + M_{32})/2 = [M_1(2-D_2+3D_3+2D_2D_3+5D_2^2D_3)]/[8(1-2D_2D_3]$

S/S moment at mid span,:

Bay I: $M_{SI} = wl^2/8 = 1.5M_1$

Bay II: $M_{SII} = wl^2/32 = 0.375M_1$

FOR BAY I: $M_P = M_{SI} – M_I$; $M_N = M_{21}$ (*Table 6.6)*

D_2	D_3	M_N / M_1	M_P/M_1
0	0	-1	0.5
0.1	0.083	-0.97	0.58
0.15	0.115	-0.96	0.64
0.2	0.143	-0.954	0.68
0.25	0.167	-0.951	0.74

FOR BAY II: $M_P = M_{SII} – M_{II}$; $M_N = M_{23}$ (*Table 6.7)*

D_2	D_3	M_N / M_1	M_P/M_1
0	0	-0.25	0.125
0.1	0.083	-0.407	0.1
0.15	0.115	-0.477	0.085
0.2	0.143	-0.546	0.068
0.25	0.167	-0.611	0.05

SWAY CASE:

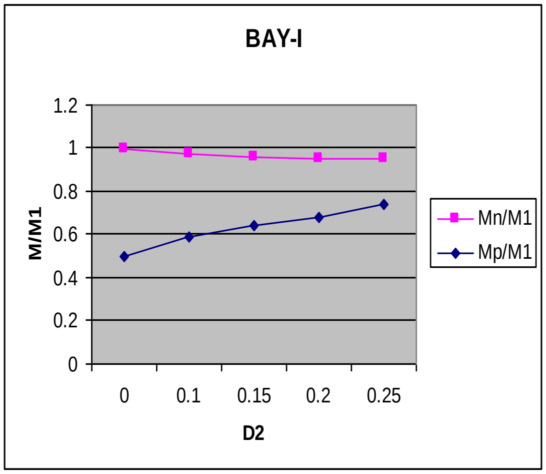
FOR BAY I: (*Table 6.8)*

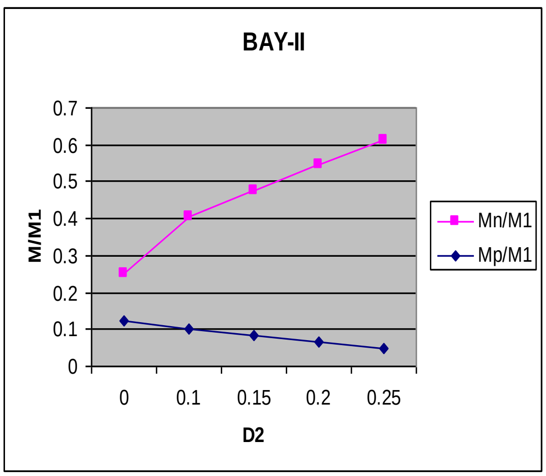
D_2	Jt.A	Jt. B	Jt. C	M_{AB}/M_1	M_{BA}/M_1 (M_n/M_1)	$M_{C/C}/M_1 = (1.5M_1- M_{11})/ /M_1$
0.1	-1.151	0.771	0.099	-0.918	-0.902	0.59
0.15	-1.187	0.83	0.063	-0.828	-0.898	0.637
0.2	-1.183	0.920	0.067	-0.714	-0.907	0.684
0.25	-1.238	0.987	0.012	-0.621	-0.914	0.737

FOR BAY II: (*Table 6.9)*

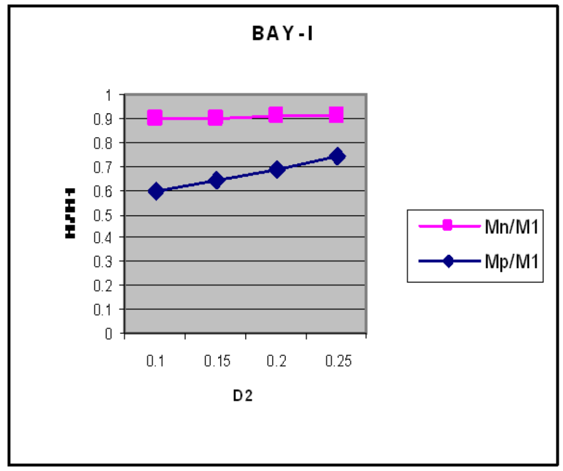
D_2	Jt.A	Jt. B	Jt. C	M_{BC}/M_1 (M_n/M_1)	M_{CB}/M_1	$M_{C/C}/M_1 = (0.375M_1- M_{22})/ /M_1$
0.1	-1.151	0.771	0.099	-0.473	-0.081	0.098
0.15	-1.187	0.83	0.063	-0.539	-0.047	0.082
0.2	-1.183	0.920	0.067	-0.582	-0.036	0.066
0.25	-1.238	0.987	0.012	-0.658	-0.004	0.044

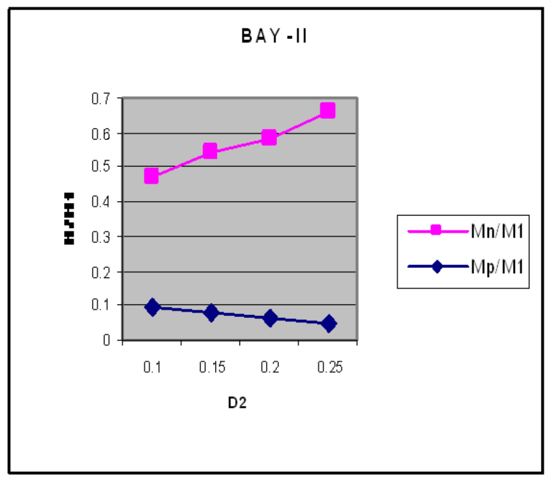
NON-SWAY CASE





SWAY CASE





CASE-III: FOR EQUAL LOAD AND VARYING SPAN

NON-SWAY CASE

Final end moments:

$M_{12} = M_1(2D_2\text{-}1) + [(D_3)(2D_2\text{-}1)(M_5 + M_1D_2\text{-}M_4D_6)]/[(1\text{-}D_2D_3)(1\text{-}D_5D_6)]$

$M_{21} = M_1(1+D_2) + [(D_3)(D_2\text{-}2)(M_5 + M_1D_2\text{-}M_4D_6)]/[(1\text{-}D_2D_3)(1\text{-}D_5D_6)]$

$M_{23} = \text{-}M_4(1+D_6) + [(D_5)(D_6\text{-}2)(M_5 + M_1D_2\text{-}M_4D_6)]/[(1\text{-}D_2D_3)(1\text{-}D_5D_6)]$

$M_{32} = M_4(1\text{-}2D_6) + [(D_5)(2D_6\text{-}1)(M_5 + M_1D_2\text{-}M_4D_6)]/[(1\text{-}D_2D_3)(1\text{-}D_5D_6)]$

Mid span moment(-ve):

$M_I = (- M_{12} + M_{12})/2$

$= M_1(2D_2-1)/2 - [(D_3)(1+D_2)(M_5+ M_1D_2-M_4D_6)]/[2(1-D_2D_3)(1-D_5D_6)]$

$M_{II} = M_4(2-D_6)/2 + [(D_5)(1+D_6)(M_5+ M_1D_2-M_4D_6)]/[2(1-D_2D_3)(1-D_5D_6)]$

A. SPAN(l,3l/4):

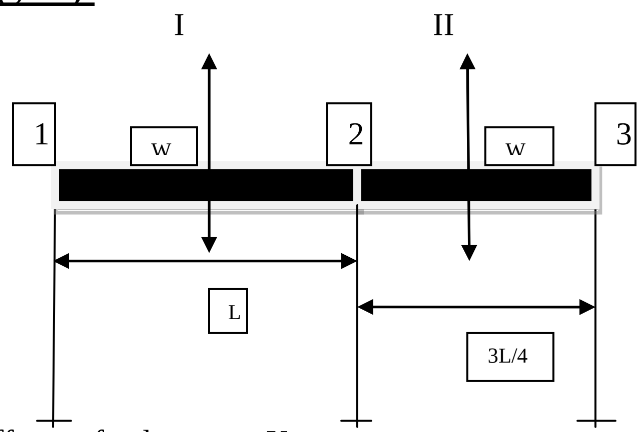


Fig.6.4

Let the stiffness of column $= K_1$

Stiffness of beam of bay I $= K_2$

Stiffness of beam of bay II $= K_3 = 4K_2/3$

$D_2= [K_2/(K_1 + K_2)]*(½)$

$D_3 = [K_2/(K_1 + K_2 + K_3)]*(1/2) = 3D_2/(3+8D_2)$

$D_5 = [K_3/(K_1 + K_2 + K_3)]*(1/2) = 4D_2/(3+8D_2)$

$D_6= [K_3/(K_1 + K_3)]*(½) = 4D_2/(3+2D_2)$

$M_1 = wl^2/12$; $M_4 = 9M_1/16$; $M_5= M_1-M_4 = 7M_1/16$

S/S moment at mid span,:

Bay I: $M_{SI} = wl^2/8 = 1.5M_1$

Bay II: $M_{SII} = wl^2/32 = 0.844M_1$

NON-SWAY CASE

FOR BAY I: $M_P = M_{SI} – M_I$; $M_N = M_{21}$ (*Table 6.10)*

D_2	D_3	D_5	D_6	M_N /M_1	M_P /M_1
0	0	0	0	-1	0.5
0.1	0.079	0.105	0.125	-1.03	0.57
0.15	0.107	0.143	0.182	-1.05	0.61
0.2	0.130	0.174	0.235	-1.07	0.65
0.25	0.150	0.200	0.286	-1.09	0.68

FOR BAY II: $M_P = M_{SII} – M_{II}$; $M_N = M_{23}$ (*Table 6.11)*

D_2	D_3	D_5	D_6	M_N /M_1	M_P /M_1
0	0	0	0	-0.56	0.288
0.1	0.079	0.105	0.125	-0.724	0.291
0.15	0.107	0.143	0.182	-0.794	0.292
0.2	0.130	0.174	0.235	-0.858	0.291
0.25	0.150	0.200	0.286	-0.920	0.289

SWAY CASE:

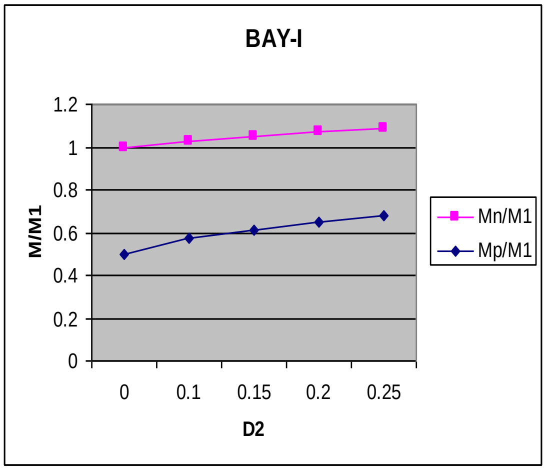
FOR BAY I: (*Table 6.12)*

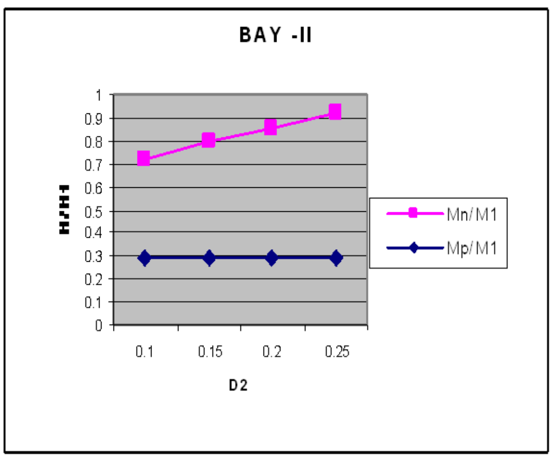
D_2	Jt.A	Jt. B	Jt. C	M_{AB}/M_1	M_{BA}/M_1 (Mn/M_1)	$M_{C/C}/M_1 = (1.5M_1-M_{11})/M_1$
0.1	-1.112	0.414	0.439	-0.889	-0.967	0.572
0.15	-1.127	0.453	0.418	-0.789	-0.993	0.609
0.2	-1.136	0.500	0.477	-0.682	-1.025	0.646
0.25	-1.142	0.552	0.394	-0.574	-1.057	0.684

FOR BAY II: (*Table 6.13)*

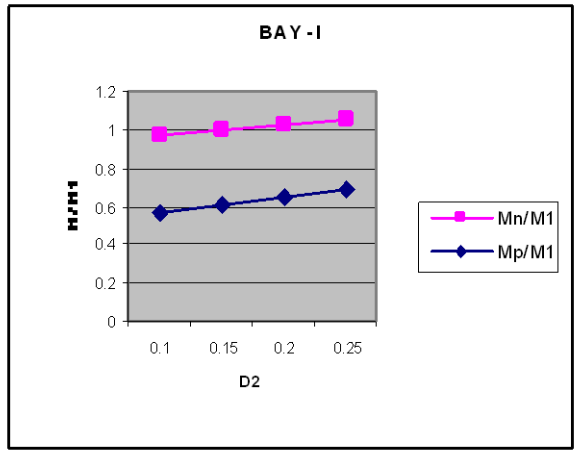
D_2	Jt.A	Jt. B	Jt. C	M_{BC}/M_1 (Mn/M_1)	M_{CB}/M_1	$M_{C/C}/M_1 = (0.844M_1 - M_{22})/M_1$
0.1	-1.112	0.414	0.439	-0.783	-0.331	0.287
0.15	-1.127	0.453	0.418	-0.847	-0.267	0.287
0.2	-1.136	0.500	0.477	-0.92	-0.179	0.290
0.25	-1.142	0.552	0.394	-0.958	-0.164	0.283

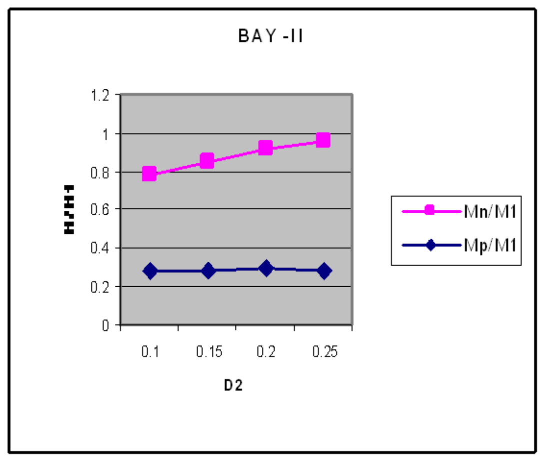
NON-SWAY CASE





SWAY CASE





B. SPAN(l, l/2):

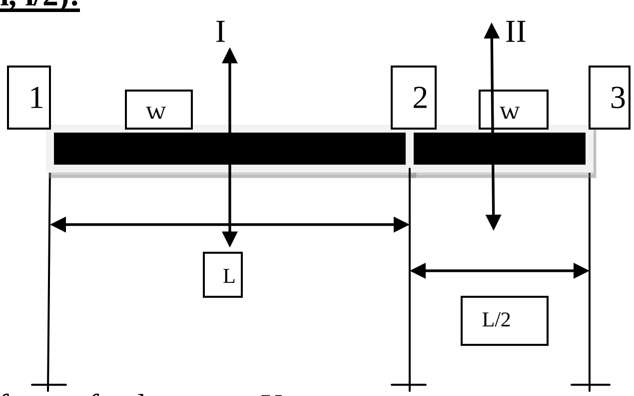


Fig.6.5

Let the stiffness of column $= K_1$

Stiffness of beam of bay I $= K_2$

Stiffness of beam of bay II = $K_3 = 2K_2$

$D_2 = [K_2/(K_1 + K_2)]*(½)$

$D_3 = [K_2/(K_1 + K_2 + K_3)]*(1/2) = D_2/(1+4D_2)$

$D_5 = [K_3/(K_1 + K_2 + K_3)]*(1/2) = 2D_2/(1+4D_2)$

$D_6 = [K_3/(K_1 + K_3)]*(½) = 2D_2/(1+2D_2)$

$M_1 = wl^2/12$; $M_4 = M_1/4$

$M_5 = M_1 - M_4 = 3M_1/4$

S/S moment at mid span,:

Bay I: $M_{SI} = wl^2/8 = 1.5M_1$

Bay II: $M_{SII} = wl^2/32 = 0.375M_1$

<u>NON-SWAY CASE</u>

<u>FOR BAY I:</u> $M_P = M_{SI} - M_I$; $M_N = M_{21}$ (*Table 6.14)*

D_2	D_3	D_5	D_6	M_N/M_1	M_P/M_1
0	0	0	0	-1	0.5
0.1	0.071	0.143	0.167	-0.987	0.58
0.15	0.094	0.187	0.231	-0.995	0.62
0.2	0.111	0.222	0.286	-1.008	0.66
0.25	0.125	0.250	0.333	-1.024	0.71

<u>FOR BAY II:</u> $M_P = M_{SII} - M_{II}$; $M_N = M_{23}$ (*Table 6.15)*

D_2	D_3	D_5	D_6	M_N/M_1	M_P/M_1
0	0	0	0	-0.25	0.125
0.1	0.071	0.143	0.167	-0.51	0.075
0.15	0.094	0.187	0.231	-0.59	0.051
0.2	0.111	0.222	0.286	-0.686	0.024
0.25	0.125	0.250	0.333	-0.763	-0.005

SWAY CASE:

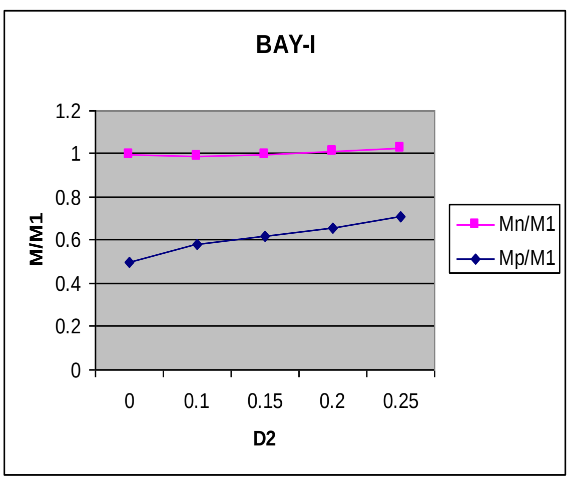
FOR BAY I: *(Table 6. 16)*

D_2	Jt.A	Jt. B	Jt. C	M_{AB}/M_1	M_{BA}/M_1 (Mn/M_1)	$M_{C/C}/M_1$ = (1.5M_1- $M_{11)/}$ /M_1
0.1	-1.195	0.726	0.0012	-0.955(Mn)	-0.873	0.586
0.15	-1.21	0.806	0.036	-0.849	-0.893	0.629
0.2	-1.212	0.900	0.059	-0.73	-0.928	0.67
0.25	-1.22	0.992	-0.088	-0.617	-0.954	0.714

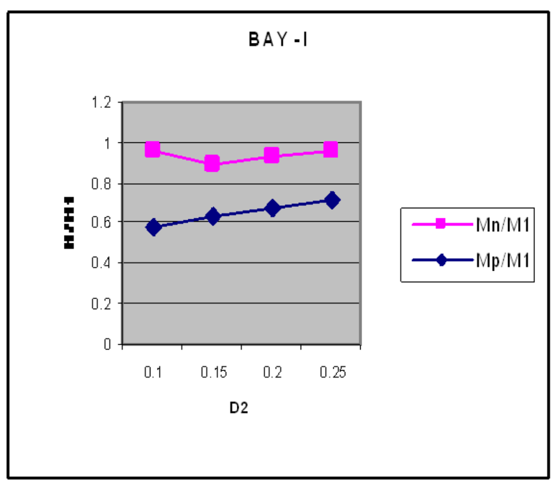
FOR BAY II: *(Table 6.17)*

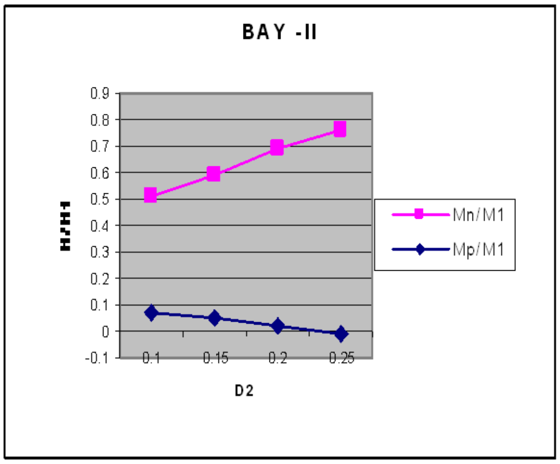
D_2	Jt.A	Jt. B	Jt. C	M_{BC}/M_1 (Mn/M_1)	M_{CB}/M_1	$M_{C/C}/M_1$ = (0.375M_1 - $M_{22)}$ /M_1
0.1	-1.195	0.726	0.0012	-0.60	-0.003	0.074
0.15	-1.21	0.806	0.036	-0.68	0.02	0.045
0.2	-1.212	0.900	0.059	-0.748	0.031(Mp)	0.0167
0.25	-1.22	0.992	-0.088	-0.82	0.042(Mp)	0.014

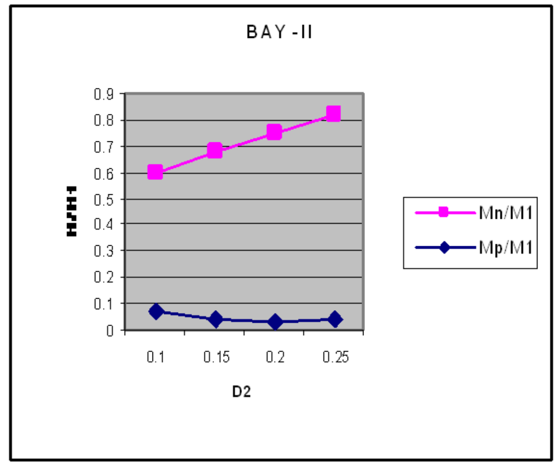
NON-SWAY CASE



SWAY CASE







C. SPAN(l, l/4):

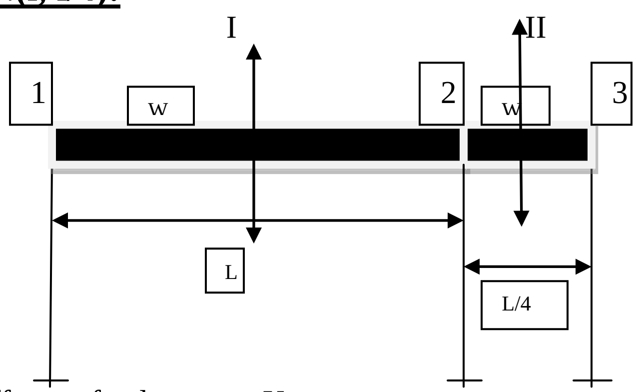


Fig.6.6

Let the stiffness of column $= K_1$

Stiffness of beam of bay I $= K_2$

Stiffness of beam of bay II $= K_3 = 4K_2$

$D_2 = [K_2/(K_1 + K_2)]*(½)$

$D_3 = [K_2/(K_1 + K_2 + K_3)]*(1/2) = D_2/(1+8D_2)$

$D_5 = [K_3/(K_1 + K_2 + K_3)]*(1/2) = 4D_2/(1+4D_2)$

$D_6 = [K_3/(K_1 + K_3)]*(½) = 4D_2/(1+6D_2)$

$M_1 = wl^2/12$; $M_4 = M_1/16$; $M_5 = M_1 - M_4 = 15M_1/16$

S/S moment at mid span,:

Bay I: $M_{SI} = wl^2/8 = 1.5M_1$

Bay II: $M_{SII} = wl^2/128 = 0.09375M_1$

NON-SWAY CASE

FOR BAY I: $M_P = M_{SI} - M_I$; $M_N = M_{21}$ (*Table 6.18)*

D_2	D_3	D_5	D_6	M_N /M_1	M_P /M_1
0	0	0	0	-1	0.5
0.1	0.055	0.22	0.25	-0.986	0.58
0.15	0.068	0.27	0.31	-1.002	0.62
0.2	0.077	0.31	0.36	-1.023	0.66
0.25	0.083	0.33	0.4	-1.051	0.70

FOR BAY II: $M_P = M_{SII} - M_{II}$; $M_N = M_{23}$ (*Table 6.19)*

D_2	D_3	D_5	D_6	M_N /M_1	M_+ /M_1	
					M_P /M_1	M_{32} /M_1
0	0	0	0	-0.062	0.031	-.032
0.1	0.055	0.22	0.25	-0.497	-0.11	0.088
0.15	0.068	0.27	0.31	-0.619	-.167	0.097
0.2	0.077	0.31	0.36	-0.733	-.226	0.093
0.25	0.083	0.33	0.4	-0.810	-0.28	0.063

SWAY CASE:

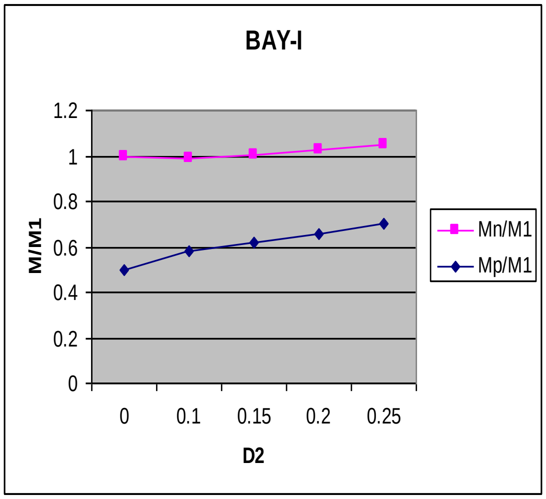
FOR BAY I: (*Table 6.20)*

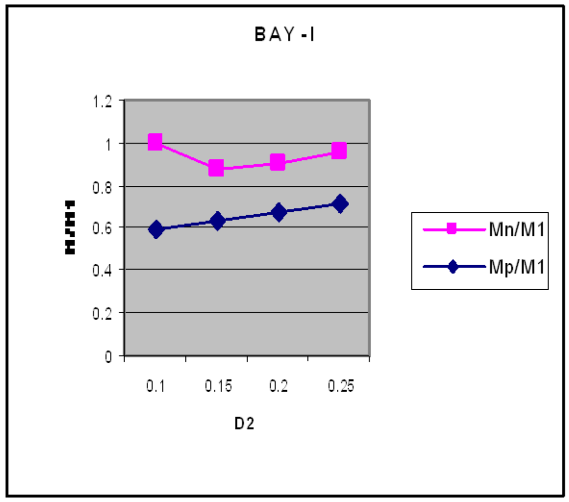
D_2	Jt.A	Jt. B	Jt. C	M_{AB}/M_1	M_{BA}/M_1 (Mn/M_1)	$M_{C/C}/M_1 = (1.5M_1 - M_{11)/} /M_1$
0.1	-1.246	0.955	-0.34	-0.998(Mn)	-0.824	0.590
0.15	-1.256	1.071	-0.404	-0.882(Mn)	-0.856	0.631
0.2	-1.242	1.206	-0.442	-0.752	-0.907	0.671
0.25	-1.22	1.33	-0.463	-0.623	-0.961	0.708

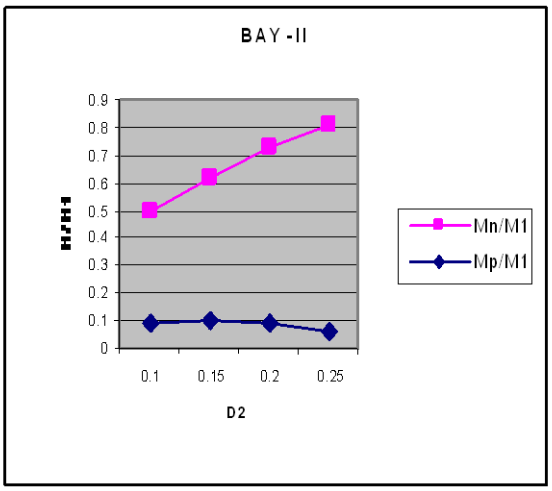
FOR BAY II: (*Table 6.21)*

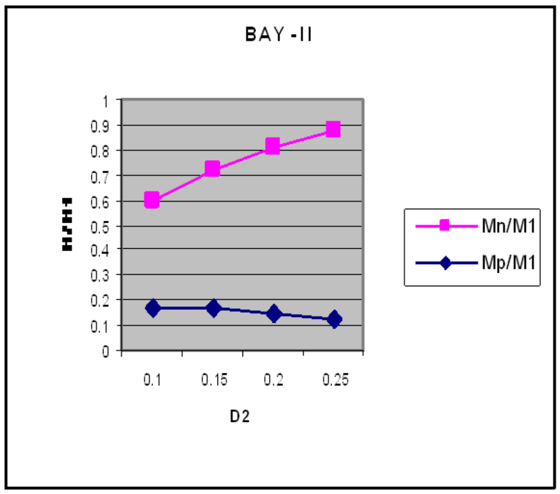
D_2	Jt.A	Jt. B	Jt. C	M_{BC}/M_1 (Mn/M_1)	M_{CB}/M_1 (Mp/M_1)	$M_{C/C}/M_1 = (0.09375M_1 - M_{22)} /M_1$
0.1	-1.246	0.955	-0.34	-0.593	0.173	-0.116
0.15	-1.256	1.071	-0.404	-0.723	0.173	-0.161
0.2	-1.242	1.206	-0.442	-0.807	0.149	-0.235
0.25	-1.22	1.33	-0.463	-0.878	0.129	-1.125

NON-SWAY CASE ***SWAY CASE***









7.STEPS TO DETERMINE THE OPTIMIZED SECTION:
D_2 -> M_N-> d_b-> d_c

- Graph of (M_N /M_1) vs D_2 is obtained.

- M_u =1.5 M_N = 2.76*b*d2

  b = 2/3d to d/2 =0.6d

  Thus depth of beam(d_b) is obtained.

- Now for a given H/L and D_2 (corresponding to M_1 value taken),

  Considering fixed column

  $D_2 = (1/2)[(I_b/ L)/(I_b/ L + I_c/ H)]$

  Or, $(d_c / d_b) = \sqrt[3]{[(1-2 D_2) / (2 D_2) * (H/L)]}$

- Graph of (d_c / d_b) vs (H/L) is obtained.

  Thus depth of column(d_c) is obtained from the graph.

8.JUSTIFICATION OF OPTIMIZATION PROCESS:

1.For a given height of column and spans of beam, the dimensions of the beam and columns are selected in such a way that the difference between the higher of the final moments at the ends of the beam and the residual maximum moment along the beam under the given loading conditions is minimum. In this way the design moment in the beam will be reduced. Thus the reinforcement as well as concrete requirement will reduce appreciably giving us the most economical section.

3.*Control of deflection:*

Evaluation of deflection is essential as beyond certain limit of it there may be a problem of serviceability and that may lead to functional failure of the structure. The maximum deflection permitted in a component as such has to be contained within the limits prescribed for that component depending on its functional aspects. These limits are mentioned in IS:456-2000.

<u>Ratios of span to effective depth for span upto 10m</u>:

Cantilever : 7

Simply supported: 20

Continuous : 26

The effective depth of the beam is taken as one fifteenth of the span of the beam in order to satisfy the deflection criteria. This value obtained is on the conservative side.

4.*Special considerations*:

In all the ductile structures we should use concrete of minimum grade M20 and the reinforcement should not be more than the grade Fe415 so that the steel is ductile.

Beams:

- The width of the beam should be greater than .3 times its depth and at least 200mm in size.
- The total depth should not be larger than one fourth the clear span to avoid deep beam action.
- As actual moments of earthquake forces can be more than the estimated values, steel both at the top and bottom face of the member at any section along its length shall be at least one fourth the maximum negative steel provided on the face of either joint.
- As seismic moments are reversible the positive steel at the joint face should be at least equal to one half the negative steel at the face.

Columns:

The "strong column weak beam " concept should be used in seismic design of columns

$$\boldsymbol{\sum M_{col} \leq 1.2\sum M_{beam}}$$

to avoid formation of plastic hinges in column. The column member shoud have the moment capacity along with the axial force in the member.

Other requirements:

- The minimum dimensions of the column should be 200mm in beams or frames of span over 5m and in columns of unsupported height above 4m it should be 300mm.
- The ratio of the shortest to longest side of the column should not be less than 0.4

9.CONCLUSION:

From the study of optimization of two bay portal frame the following conclusions can be made:

- Variation of the higher of the final moments at the ends of the beam(M_N) and the residual maximum moment along the beam(M_P) with respect to the rotation factor of the beam(D_2) is obtained for the following cases and a comparison is made between non-sway and considering sway cases :

  Case-I: For equal loading and spans in both the bays

  Case-II: For varying load and equal spans (Considering both bays)

  A. Loads(w, w/2) B. Loads(w, w/4)

  Case-III: For equal load and varying spans (Considering both bays)

  A. Span(l,3l/4) B. Span(l, l/2): C. Span(l, l/4)

- *Case-I: For equal loading and spans in both the bays:*

  With increasing value of D_2, M_N is always double of $M_{P.}$

- *For varying load and span:*

  Bay-I: .

  - With increasing value of D_2, M_N and M_P converge towards each other.
  - It is observed that when sway is considered, M_N and $M_{P.}$ are closer to each other as compared to non-sway case
  - In case of varying span, for lower values of D_2 (sway cases), negative end moment at the outer joint is considered as M_N, as it becomes higher than the end moment at the inner joint.

Bay-II:

- With increasing value of D_2, M_N and M_P diverge from each other. But the values are very less as compared to the values of Bay-I.
- It is observed that when sway is considered, divergence of M_N and $M_{P.}$ is more as compared to non-sway case
- And in case of varying span (l, l/4), moment at the centre of the span becomes negative and end moments at the outer joint become positive(considered as the maximum positive moment of the span)

10.FUTURE WORKS:

- The variation of the higher of the final moments at the ends of the beam(M_N) and the residual maximum moment along the beam(M_P) with respect to the rotation factor of the beam(D_2) can be obtained for the following cases.:

1. Pinned end column for varying spans and load.
2. Variation of section of the beam(parabolic)

   As we have found, variation of moments throughout the section is very high. So we can vary the section of the beam according to the requirements to get an economic section.

- There is also scope for future studies. Consideration of (i) three dimensional portal frames; (ii) economy aspects in terms of costs and benefits; and (iii) system reliability aspects, are some of the areas where scope exists for extending the model.

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